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Method for the production of cast steel strip

The invention relates to a method for the production of cast steel strip, wherein, in a continuous procedure, a steel melt is cast into a casting gap, the longitudinal sides of which are formed by walls that move during the casting process, to form the steel strip, and the steel melt, which is present above the casting gap in a melt pool, is held under an atmosphere containing nitrogen and hydrogen. A method of this type is described, for example, in EP 0 409 645 B1.

A fundamental problem in the production of steel strip cast directly from a steel melt is that of conducting the casting process in such a way that an optimal, high-quality strip surface is obtained. In practice, it has thus been found that significant surface defects are caused by the formation of cracks and the entrapment of oxides ("scums") in the regions of the cast strip in proximity to the surface. In many cases, cast strips produced by strip-casting also conventionally have a heterogeneous surface structure, resulting in non-uniformity of the perceptible shine of the finished cast strip. A "heterogeneous shine" of this type is a further quality defect restricting the saleability of cast strip.

The aforementioned EP 0 409 645 B1 proposes, for improving the surface characteristics of cast strip, forming dimples in the elements delimiting the casting gap in the device used for casting the strip, which elements move during the casting operation. In addition, a gas mixture is to be blown into the area of what is known as the "meniscus", at which the melt enters into contact with the dimples in the moving elements.

The gas mixture is to contain 30% by volume to 90% by volume of a gas soluble in metal. An insoluble gas may also be provided.

EP 0 409 645 B1 cites N_2, H_2, CO_2, CO and NH_4 as gases soluble in metal suitable for carrying out the known method. Argon and helium are given as examples of an insoluble gas. However, only the effects of gas mixtures comprising N_2 and Ar contents are described specifically in this regard.

According to EP 0 409 645 B1, the effect of the gas mixture blown into the meniscus area in combination with the dimples formed in the moving elements, which delimit the casting gap, is that any air present in the dimples and gases issuing from the cast metal are expelled and the blown-in gas enters the dimples to replace them. Subsequently in the process, the melt enters the dimples. As a result of its solubility, the gas located therein is absorbed by the melt, so the melt may enter the dimples unimpeded. A temporary interlocking linkage, which ensures that there is no relative movement between the elements and the solidified shell formed as a result of the solidification of the melt on the moving elements, may thus be achieved between the solidifying melt and the moving elements. According to the information provided in EP 0 409 645 B1, such relative movement causes the formation of surface cracks.

EP 0 409 645 B1 also proposes protecting from oxidation the melt present above the casting gap in what is known as the "melt pool" in that the melt pool is held under a non-oxidising atmosphere. It is regarded as being preferable if the atmosphere is formed from a nitrogen/argon gas mixture.

What are known as twin-rollers, in which the elements, which delimit the casting gap at the longitudinal sides thereof and

move during the casting operation, are in the form of casting rollers, which are rotated in opposite directions and cooled during the casting operation, are conventionally used for strip-casting. A high degree of technical complexity, which complicates the regularly required maintenance of the casting rollers, is necessary for forming the dimples required according to EP 0 409 645 B1, for example, in the surfaces of the casting rollers of a twin-roller.

Moreover, practical tests have revealed that the problem of the production of surface defects owing to the formation of cracks and entrapment of oxides may not be solved even if the surface of the melt pool present above the casting gap is sealed off against atmospheric oxygen, as advocated in EP 0 409 645 B1, by a non-oxidising atmosphere.

The object of the invention was accordingly to specify a process allowing the production of high-quality steel strips having a significantly improved surface composition compared to the prior art.

Starting from the above-described prior art, this object has been achieved by a method for the production of cast steel strip, wherein, in a continuous procedure, a steel melt is cast into a casting gap, the longitudinal sides of which are formed by walls that move during the casting process, to form the steel strip, and the steel melt, which is present above the casting gap in a melt pool, is held under an atmosphere containing nitrogen and hydrogen, wherein, according to the invention, the hydrogen content of the atmosphere is greater than 0 mol % to 10 mol %, and the Cr, Mo, Nb, Si, Ti, Ni, Mn, C or N contents %Cr, %Mo, %Nb, %Si, %Ti, %Ni, %Mn, %C or %N of the cast steel melt, which are selectively present in each case for adjusting the characteristics of the steel strip, are

in each case selected in such a way that for the ratio Cr_{eq}/Ni_{eq} formed from the Cr equivalent Cr_{eq} and the Ni equivalent Ni_{eq}, the following applies:

$$Cr_{eq}/Ni_{eq} \geq 1.7,$$

wherein $Cr_{eq} = \%Cr + 1.37\ \%Mo + 2\ \%Nb + 1.5\ \%Si + 3\ \%Ti,$

$Ni_{eq} = \%Ni + 0.31\ \%Mn + 22\ \%C + 14\ \%N + \%Cu.$

The invention is based on the realisation that a specific minimum content of H_2 in the atmosphere covering the melt pool has a beneficial effect on the surface composition of the steel strip obtained if, at the same time, a steel alloy is used, the alloy contents of which are coordinated in such a way that the ratio formed from its Cr equivalent and its Ni equivalent is at least 1.7. The formulae specified for calculating the Cr equivalent and Ni equivalent correspond to those determined by Hammar and Svensson in "Solidification and Casting of Metals", The Metals Society, London, 1979, pages 401 to 410.

In addition to the chromium equivalent Cr_{eq}, the nickel equivalent Ni_{eq} is a characteristic providing information regarding the structural contents of stainless steels of the type processed in the manner according to the invention. Nickel and chromium are present in these types of steel in considerable mass contents. Ni is an austenite former, while Cr is a ferrite former.

The contents of the alloy elements specified in the formulae for determining the Cr and Ni equivalents may, of course, also be "0", so not each of the relevant elements necessarily has to be present in steel processed in the manner according to the invention. Examples of typical steel alloys that may be

processed in the manner according to the invention include, for example, the steels pertaining to Class AISI 304 and comparable austenitic Cr/Ni steels. Ferritic high-grade steels and carbon steels are, however, also suitable for the method according to the invention, since in the conventional procedure for casting these types of steels, too, scums and cracks appear at the surface of the strip. These material defects may also reliably be controlled using the method according to the invention on ferritic high-grade steels and carbon steels.

The hydrogen present, according to the invention, in the atmosphere protecting the melt pool with respect to the environment causes the binding of oxygen introduced into the region of the melt pool, for example, via the elements, which move during the casting operation, of the casting device or other inevitable non-sealed areas. The risk of reoxidation of the melt is therefore effectively counteracted. The entrapment of oxides ("scums") in the surface of the cast strip is thus reduced to a minimum.

The presence of hydrogen in the atmosphere above the melt pool also assists the breaking-down of the nitrogen into its atomic components (N_2 - >2 N). In this (atomic) state, the nitrogen may be absorbed at the surface and diffuse into the steel, which is alloyed in accordance with the prescriptions according to the invention. This ensures homogeneous solidification, which is reflected in good imprinting characteristics, and prevents crack formation. The formation of the surface cracks is therefore reliably prevented, without the surface of the walls entering into contact with the melt having to be configured in a particular manner. In the case of the procedure according to the invention, there is therefore no need, especially if a twin-roller is used, for complex

manufacture and maintenance processes, such as are inevitable in the prior art considered at the outset. Instead, the walls delimiting the casting gap may be provided with a stochastic unevenness distribution, such as is conventionally produced by an abrasive blasting process (for example, $R_a > 40\ \mu m$, preferably $> 60\ \mu m$, $R_z > 7\ \mu m$, preferably $> 10\ \mu m$).

Adjusting the hydrogen content of the atmosphere to at least 0.5 mol % reliably ensures that the effect according to the invention caused by the presence of the hydrogen is achieved. In order also to ensure that the hydrogen does not react explosively with the ambient oxygen, the hydrogen content of the atmosphere may be limited to no greater than 7.5 mol %.

If it should be found that the solubility of the nitrogen in the steel has undesirable repercussions, the supply of nitrogen in the protective atmosphere above the melt pool may be reduced in that a noble gas, preferably argon, is added to the atmosphere. It is accordingly expedient to vary the nitrogen content in the protective atmosphere within a range, the lower limit of which corresponds, if a third gas is present in the gas mixture, to 30 mol %, and the upper limit of which corresponds, in the absence of a third gas, to the remainder apart from the respective H_2 content.

A further important configuration of the invention provides that, for the ratio Cr_{eq}/Ni_{eq}, the following applies: $Cr_{eq}/Ni_{eq} \geq 1.8$. It has surprisingly been found that in the processing according to the invention of steels for which this required ratio of the Cr equivalent to the Ni equivalent is adhered to, an optimal surface appearance may be ensured. In the case of steels having a composition of this type, which are held during the casting process, in the manner according to the invention, under an atmosphere containing hydrogen, there is

no longer heterogeneous shine. Instead, the observer sees a uniform, consistent surface shine of the finished strip, which is no longer marred by spots or comparable inhomogeneities such as grey mottling, streakiness or similar appearances. This may be accounted for by the fact that, in the mode of manufacture according to the invention, the transfer of heat between the moving walls, delimiting the casting gap, and the melt is rendered uniform in that, as described above, any oxygen conveyed by the relevant walls is bound by the atmospheric hydrogen, and the nitrogen is in a state in which it may easily diffuse into the steel melt. On leaving the casting gap, the steel, which enters into contact with the walls, accordingly has in the region of its surface a uniform structure, which is a prerequisite for the formation of a uniform surface shine.

In addition to the above-described advantages of the invention, a basic effect of the increase according to the invention in the ratio Cr_{eq}/Ni_{eq} and the addition of hydrogen to the atmosphere above the melt pool is that the casting capacity rises significantly above that which may be achieved using the conventional procedure. This increase in casting capacity is obtained even if the lower limit, specified according to the invention, for the ratio Cr_{eq}/Ni_{eq} is adhered to and hydrogen is added within the range specified according to the invention, and may be further increased by increasing the value of the ratio Cr_{eq}/Ni_{eq} and the content of hydrogen in the atmosphere above the melt.

The effects achieved by the invention are obtained independently of the respective sulphur content of the processed melt. There is therefore no need to restrict the application of the invention merely to specific steel alloys.

The invention will be described below in greater detail with reference to a drawing illustrating embodiments. The figure is a schematic side view of a twin-roller.

The twin-roller 1, which is configured in a manner known *per se* and is used as a device for casting steel strips B, having a thickness from 1 mm to 10 mm, from a steel melt, comprises two casting rollers 2, 3, which rotate in opposite directions during the casting operation and delimit between them a rectangular casting gap 4 in the longitudinal direction thereof. The circumferential surfaces of the casting rollers 2, 3 form the walls, which move during the casting operation, of the casting gap 4. The short sides of the casting gap 4 are sealed by side plates (not shown).

The steel melt is cast from an overflow (also not shown) into the casting gap 4 using a dip tube 5. Accumulated melt forms a melt pool 6 above the casting gap 4.

The region above the melt pool 6 is sealed off with respect to the environment by an enclosure 7. Above the surface of the melt pool 6, the composition of the atmosphere A inside the enclosure 7 differs from that of the open environment U outside the enclosure 7.

Casting tests were carried out on melts E11, E12, E13, E21, E22, E23 and V11, V12, V13 using the device 1. The tests carried out on the melts E11 to E23 took place in the manner according to the invention, while the casting tests V11 to V13 were used to demonstrate the results obtained in the conventional mode of manufacture.

The compositions of the respectively cast steel melts E11 to E23 and V11 to V13 are specified in Table 1. In the case of

the melts V11 to V13, which were processed for the purposes of comparison, the ratio Cr_{eq}/Ni_{eq} is less than 1.7, while the ratio Cr_{eq}/Ni_{eq} for the steels E11 to E13 is between 1.7 and 1.8, and for the steels E21 to E23 is more than 1.8.

The melts were, in each case, cast to form strips of varying thickness. The N_2, Ar and H_2 content of the composition of the atmosphere A in the enclosure 7 above the melt pool 6 was, in each case, varied. The relevant strip thicknesses and the further operating parameters are recorded in Table 2.

Table 2 also contains the results of the assessment of the surface composition of the strips produced from the melts V11 to V13 and E11 to E23. In the case of the comparative examples V1 to V3, it was found that although varying the N_2 and Ar contents of the atmosphere A allowed the occurrence of scums and cracks to be influenced, only the addition according to the invention of H_2 to the atmosphere A causes a significant increase in the reliability with which a high-quality cast steel strip product, the visual appearance of which also meets strict requirements, may be provided.

The tests that were carried out reveal that the casting capacity may be significantly increased by applying the invention. It could thus be demonstrated that an increase in the ratio Cr_{eq}/Ni_{eq} causes a corresponding rise in the casting capacity. Diagram 1 shows in graph form the relationship between the casting capacity and the ratio Cr_{eq}/Ni_{eq}.

LIST OF REFERENCE SIGNS

B	Steel strip
1	Twin-roller
2, 3	Casting rollers
4	Casting gap
5	Dip tube
6	Melt pool
7	Enclosure
A	Atmosphere above the melt pool 6
U	Environment

	C	Si	Mn	P	S	Cr	Mo	Ni	Al	B	Co	Cu	N	Nb	Ti	Cr_{eq}/Ni_{eq}
V1	0.045	0.29	1.39	0.025	0.001	17.01	0.20	8.46	0.003	0.0004	0.13	0.18	0.046	0.01	0.001	1.66
V2	0.048	0.39	0.41	0.026	0.001	17.21	0.12	8.42	0.003	0.0004	0.13	0.20	0.064	0.01	0.002	1.68
V3	0.045	0.30	1.25	0.026	0.003	17.14	0.22	8.40	0.003	0.0004	0.02	0.25	0.060	0.01	0.001	1.65
E11	0.038	0.36	1.04	0.022	0.001	18.00	0.52	8.93	0.003	0.0004	0.17	0.02	0.039	0.01	0.001	1.78
E12	0.042	0.44	1.26	0.025	0.001	18.28	0.28	8.52	0.003	0.0006	0.11	0.29	0.051	0.01	0.002	1.79
E13	0.050	0.46	1.27	0.025	0.013	18.10	0.30	8.63	0.003	0.0004	0.16	0.26	0.054	0.01	0.007	1.73
E21	0.047	0.30	1.30	0.020	0.003	18.06	0.36	8.09	0.003	0.0004	0.17	0.22	0.054	0.01	0.009	1.81
E22	0.039	0.33	1.26	0.024	0.001	18.04	0.16	8.01	0.003	0.0004	0.09	0.16	0.057	0.01	0.001	1.84
E23	0.039	0.40	1.26	0.024	0.001	18.14	0.27	7.99	0.003	0.0004	0.02	0.16	0.050	0.01	0.010	1.89

All data specified in % by weight, the remainder being iron and conventional impurities

Table 1

	Cr_{eq}/Ni_{eq}	Strip thickness [mm]	Roller unevenness [µm]		Composition of gas mixture supplied [mol %]			Surface defects on the strip		
			Rz	Ra	N_2	Ar	H_2	Cracks	Scums	Heterogeneous shine
V11	< 1.7	2.8	100	20	53	47	0	None	Some	Distinct
V12		2.7	92	19	18	77	5	None	None	Distinct
V13		2.7	90	18	95	0	5	None	None	Distinct
E11	≥ 1.7	3.0	82	17	70	30	0	Some	Some	Slight
E12		3.0	82	17	15	80	5	Some	None	Slight
E13		2,7	102	20	81	14	5	None	None	Slight
E21	≥ 1.8	2.9	86	18	48	52	0	Many	Some	None
E22		2.7	78	16	23	72	5	Some	None	None
E23		3.0	78	16	85	10	5	None	None	None

Table 2